

Lightweight Materials and Safety

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CARB Workshop

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Factors Influencing Safety

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1. Drivers & driving environment

“crashworthiness factors are overwhelmed in importance by driver factors. Crashworthiness factors are relevant only when crashes occur.”

- Leonard Evans, “CAFE – why it is so difficult to estimate its effect on traffic fatalities and fuel use”, Presented at TRB, Jan 2003

2. Crashworthiness

Vehicle design and compatibility

3. All else being equal:

Vehicle size and weight

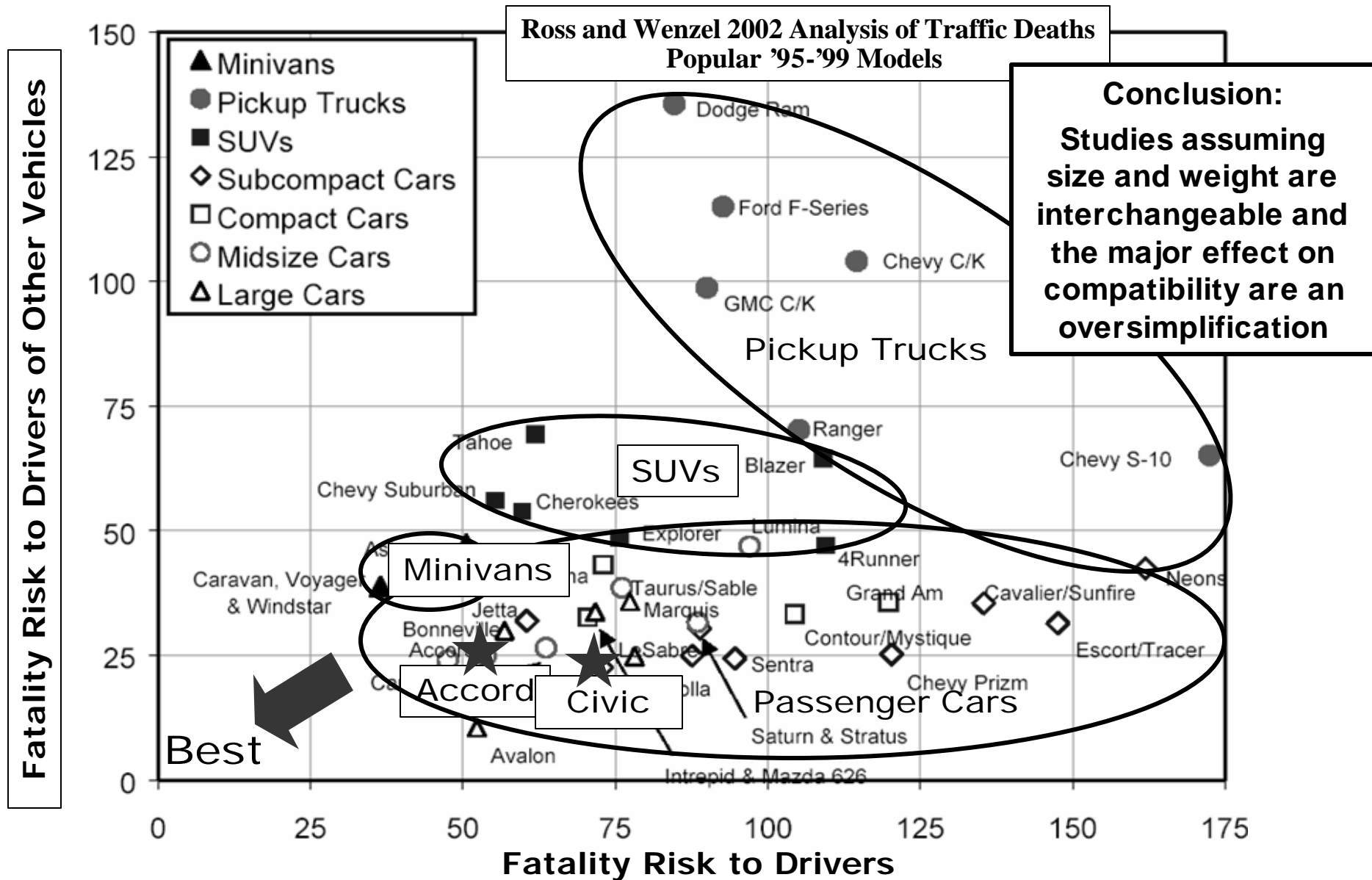
Crashworthiness:

1. Occupant deceleration:
 - Vehicle weight
 - Space for crush and to absorb energy
2. Occupant protection inside compartment:
 - Strength and rigidity to prevent intrusion
 - Restraint system's ability to cushion and protect occupants within the passenger compartment

Crash Compatibility Factors

- Vehicle protective structure **geometry**
 - Differences in vehicle structural geometry increases intrusion into occupant compartment of one vehicle
 - Unlike cars, light trucks have few “mating surface” requirements
- Relative vehicle and occupant compartment **stiffness**
 - The stiffer vehicle will crush less than the softer vehicle
 - Can increase intrusion into the occupant compartment of the softer vehicle
- Relative vehicle **weight**
 - Heavier vehicle experiences lower crash energy absorption
 - Lighter vehicle experiences higher energy absorption

Impact of Drivers, Roads, and Vehicles



Impact of Vehicle Design

- Energy management and rollover prevention are the most important factors for effective safety protection
- **1996-99 mid-size SUVs had a 50% higher fatality rate for their occupants than small SUVs, despite being 850 pounds heavier (Kahane 2003)**

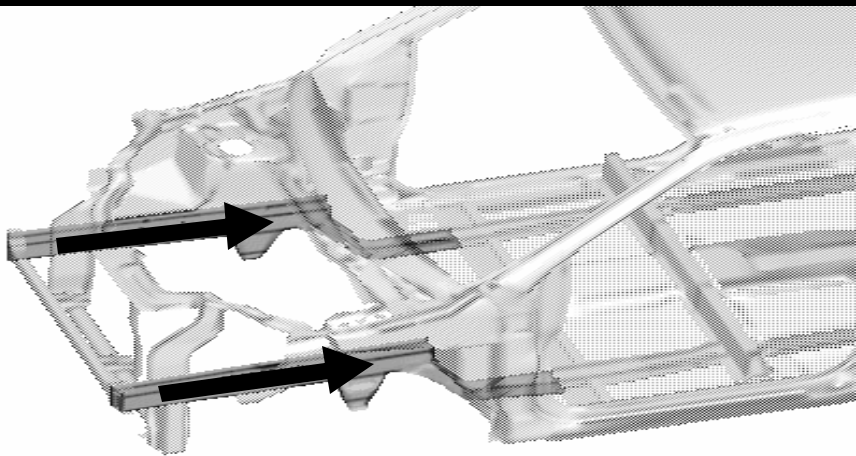
	Avg curb weight (p 197)	Fat. In My Vehicle (p 198)	Other Veh + Peds Fat (p 198)	Rollover Occ Fat (p 202)	Fixed-Object Occ Fat (p 202)	Ped-Bike-MC Fat (p 202)	heavy truck Fat in LTV (p 202)
Small SUVs	3,174	6.09	4.38	1.53	1.98	2.11	1.14
mid-size SUVs	4,022	9.16	4.52	4.42	2.64	1.72	0.84

- Difference cannot be explained by driving behavior:
 - Kahane 2003 found more “imprudent driving behavior per fatal-crash involved driver” for small SUVs than mid-size SUVs
- Rollover fatality rates in small SUVs 65% lower than in mid-size SUVs
- Fatality rates in collisions with fixed objects also significantly lower for small SUVs

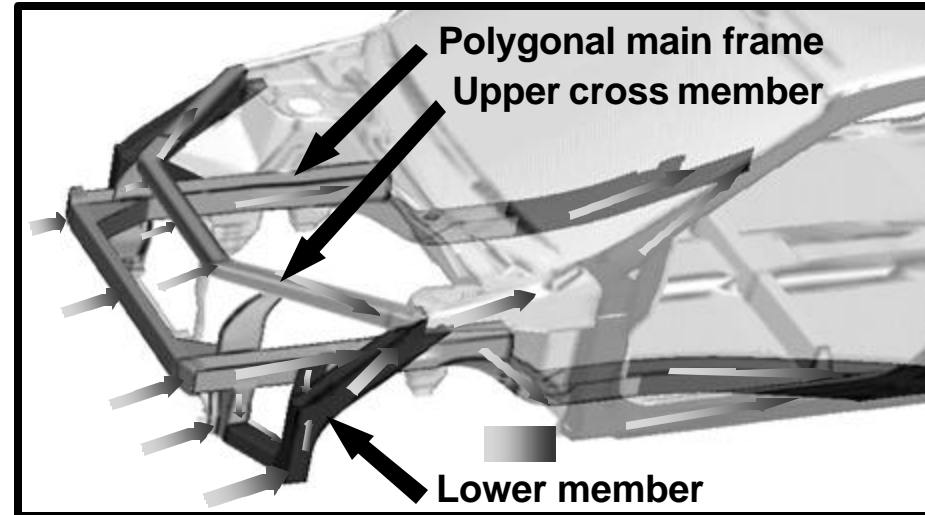
Compatibility efforts

- Safety is primarily a design issue. 2006 Civic is a case study of how to engineer a small car for highest safety performance

Previous Body



New ACE™ Body



- The ACE structure achieves its advantages by moving from *concentration to dispersion* of crash force, and optimizing crush stroke and energy management

ACETM Body Structure

- Despite shorter front end & increased weight from previous models, intrusion values are reduced – especially in the driver's footwell
 - Source: IIHS

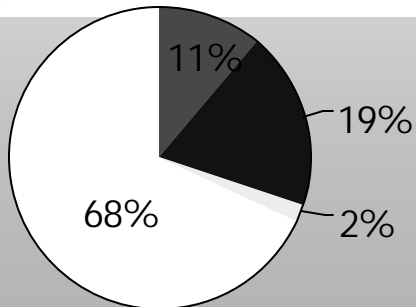
Passenger Compartment Intrusion Comparison

Model Year	Footwell Intrusion			Brake Pedal Intrusion
	Left	Center	Right	
2006	8	9	6	7
2001	11	11	10	8
1997	24	22	18	17

High Strength Steel Utilization

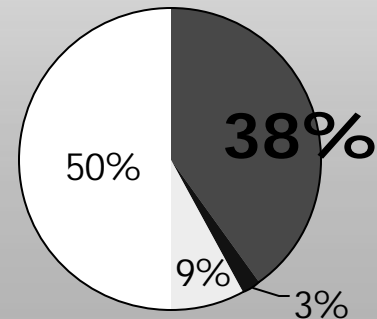
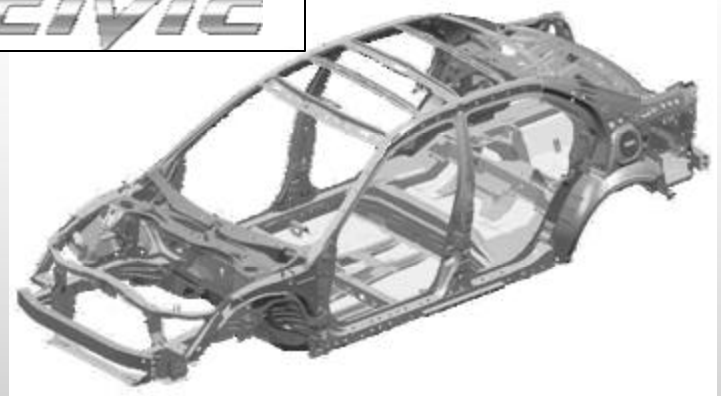
- High strength steel allows weight reduction and/or improved performance
- Usage of 590 MPa steel has more than tripled (11% → 38%)

05MY Civic



Usage Rate: 32%

CIVIC

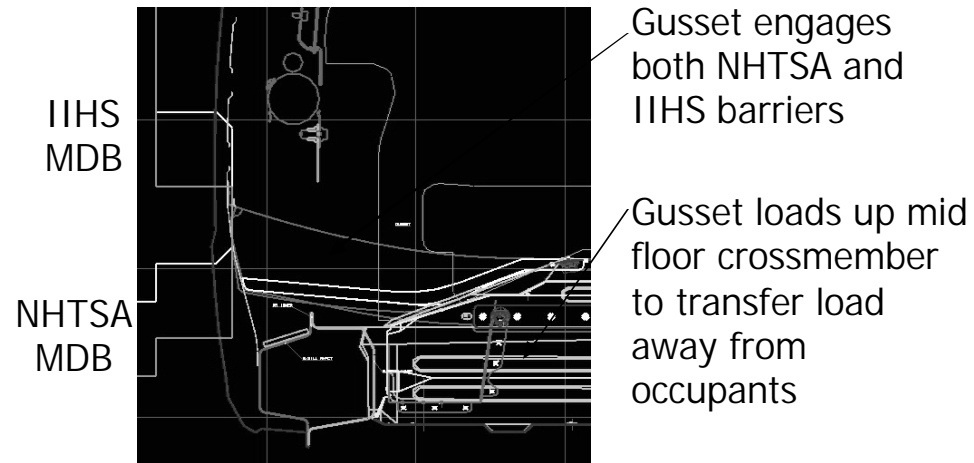
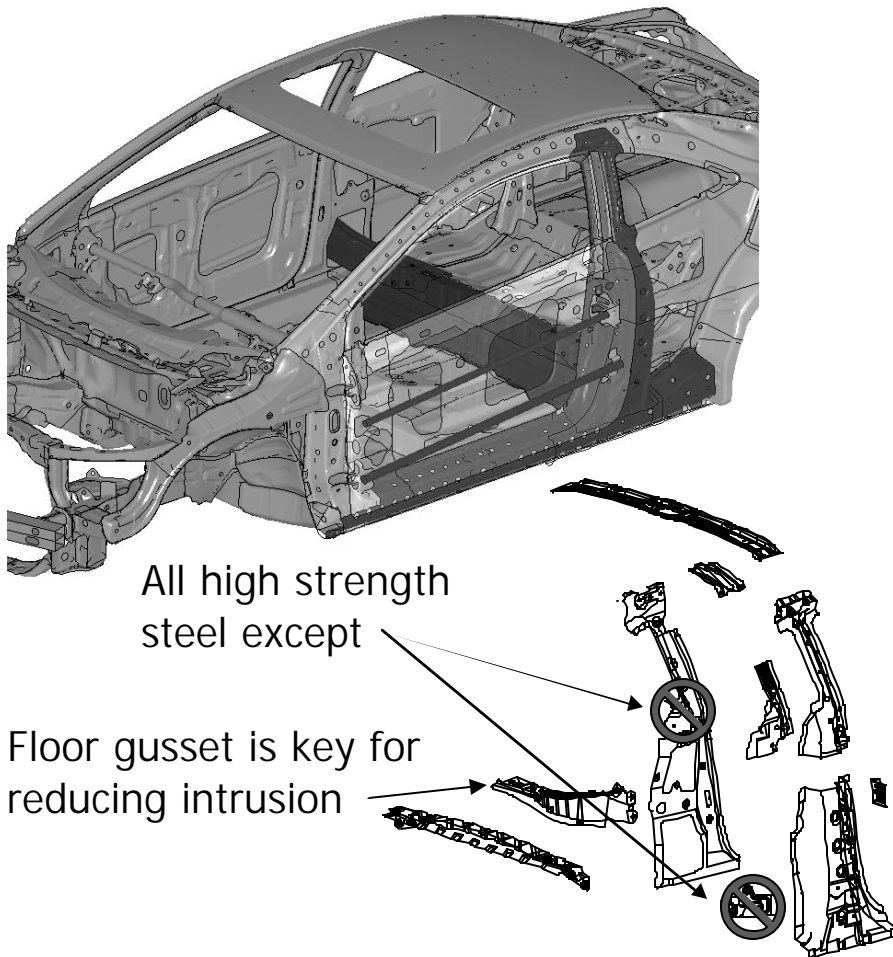


Usage Rate: 50%

50% of body now high strength steel

Side Impact Construction (Coupe)

- Most of side impact construction is high strength steel
- Concept is similar to previous model – but had to be optimized to account for NHTSA & IIHS modes



***IIHS Side Impact score*
improved one rating
category with addition of
high strength steel***

* Internal test data

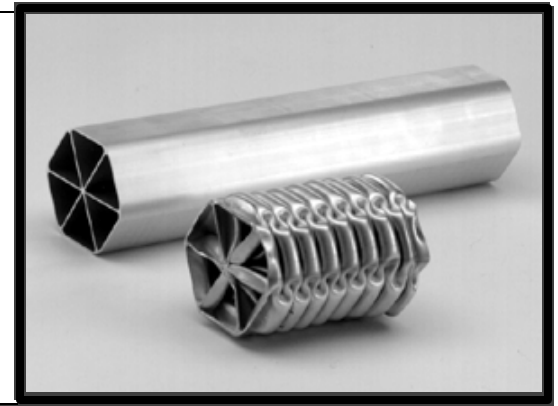
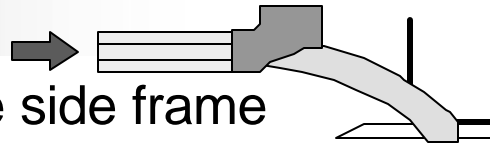
2000 Insight - New Lightweight Aluminum Body Structure

Side frame structure to control frontal crash energy

First stage

Front end area of the side frame

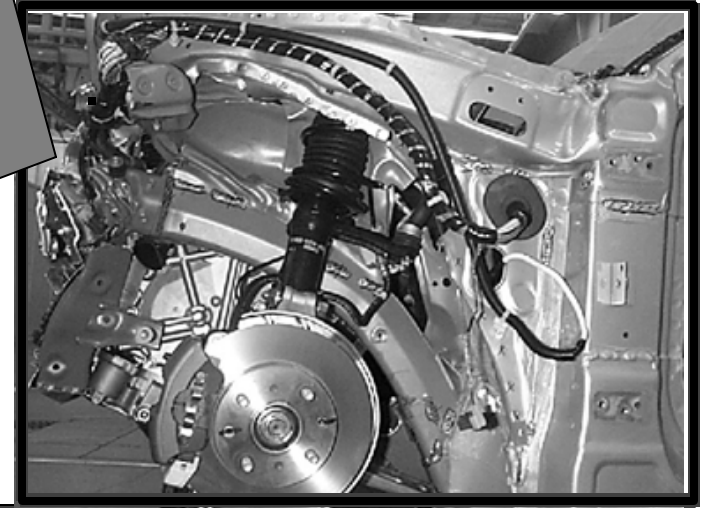
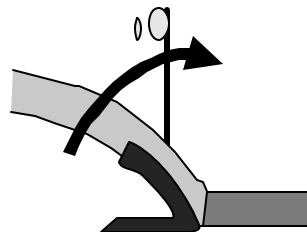
The hexagonal cross section member is compressed for efficient absorption of impact energy.



Second stage

Rearward area of the side frame

Controls impact energy by bending and rotating.



Implications for Size and Weight

- (1) Safety impacts of size and weight are small compared to driver, driving influences, and vehicle design influences
- (2) Safety impacts difficult to quantify

Impacts of Weight and Size in Safety

Vehicle Interactions with Fuel Economy

Crash Effects

**Increase
Efficiency**



Does Not Affect Safety

**Decrease
Weight**



- **Increases deceleration in crashes with other vehicles or yielding object**

**Decrease
Size**



- **Can effect interior “survival” space**
- **Can affect exterior “crush” space to mitigate deceleration**

Vehicle Interactions with Fuel Economy

	<u>Crash Effects</u>	<u>Pre-Crash</u>
Increase Efficiency	Does Not Affect Safety	No effect
Decrease Weight	<ul style="list-style-type: none">Increases deceleration in crashes with other vehicles or yielding object<ul style="list-style-type: none">deceleration of other vehicle is lowerlittle effect on rigid barrier impacts	Lighter vehicles of comparable size can handle and brake better
Decrease Size	<ul style="list-style-type: none">Can effect interior “survival” spaceCan affect exterior “crush” space to mitigate decelerationSurvival and crush space also depends on vehicle structure design and materials used	<div>May be more likely to avoid collisions</div> <div>including with pedestrians and cyclists</div>
Vehicle configuration/geometry	<ul style="list-style-type: none">Taller vehicles tend to be safer for occupants of that vehicle and do more harm to occupants of other vehicles <div>Taller vehicles may inflict greater harm on pedestrians and cyclists</div>	Vehicle with higher center of gravity are more likely to rollover

Theoretical Impact of Light Materials

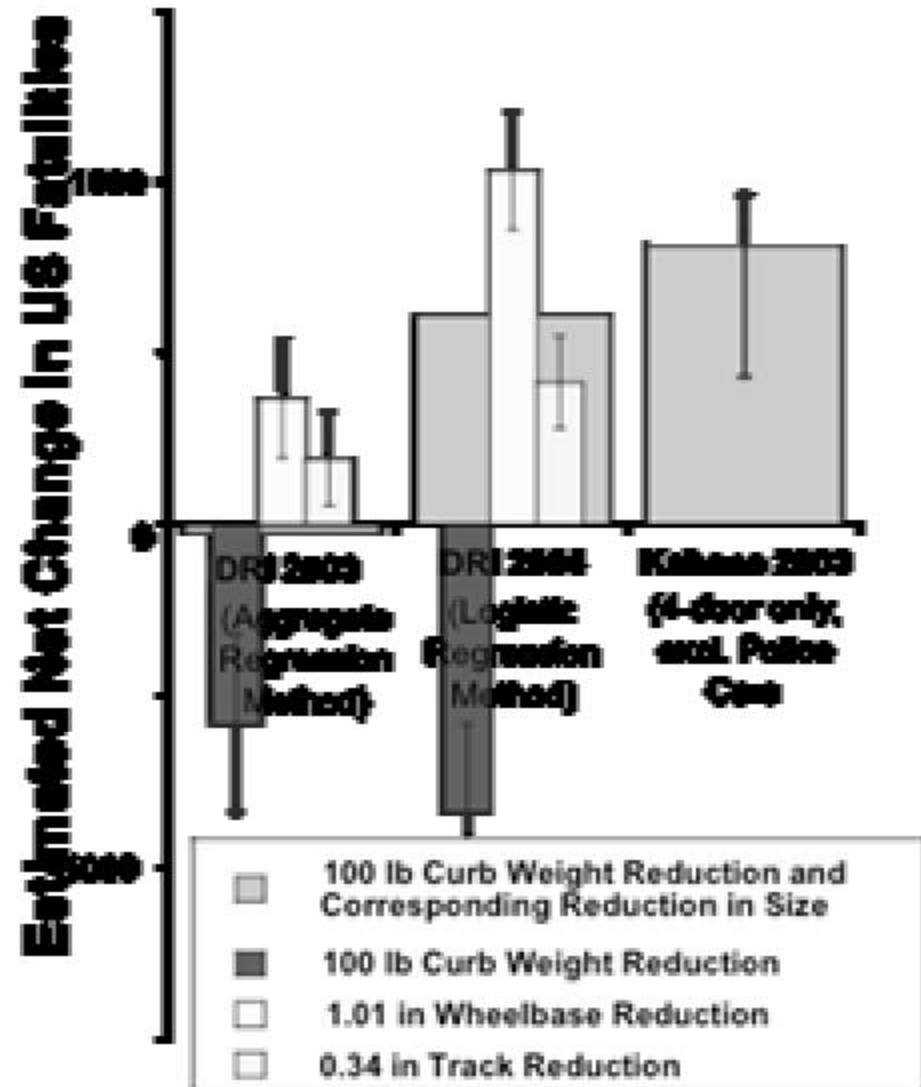
- Reducing vehicle weight reduces the crash forces that must be managed in a crash – for both vehicles
 - If interior space and the space for managing the crash forces are maintained the reduced weight makes it easier to manage the crash forces and protect the occupants of both vehicles.
- High-strength steel and aluminum have better crash characteristics than conventional steel
 - The safety benefit of high-strength steel is the primary reason for its rapidly increased market penetration.
 - Aluminum provides more uniform management of crash forces.
- Reducing vehicle weight improves vehicle handling and braking.

2003 Kahane Study

- The 2003 Kahane study was a good study, **but Kahane asked the questions incorrectly**
 - Assumed size and weight are completely correlated
 - Assumed a direct correlation between size/weight and safety
- Advances in crash technology and materials require a more sophisticated analysis.
 - Critical to analyze separately the effect of size and weight on safety

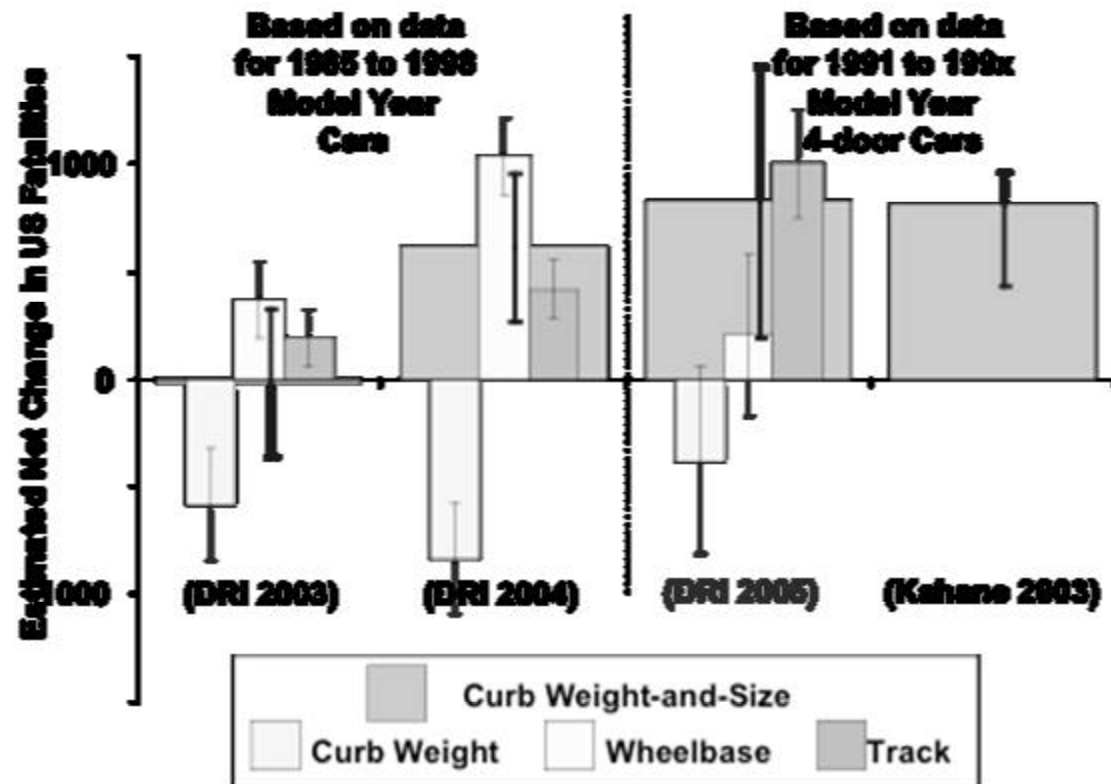
DRI Results: SAE 2005-01-1354

- Independent effects of Passenger Car and LTV “Curb Weight”, “wheelbase”, and “track” reduction on fatalities were assessed
- Overall conclusions were that weight and size reductions have opposite effects on fatalities
 - “Curb weight” reduction decreases fatalities
 - “Wheelbase” and “track” reduction increases fatalities



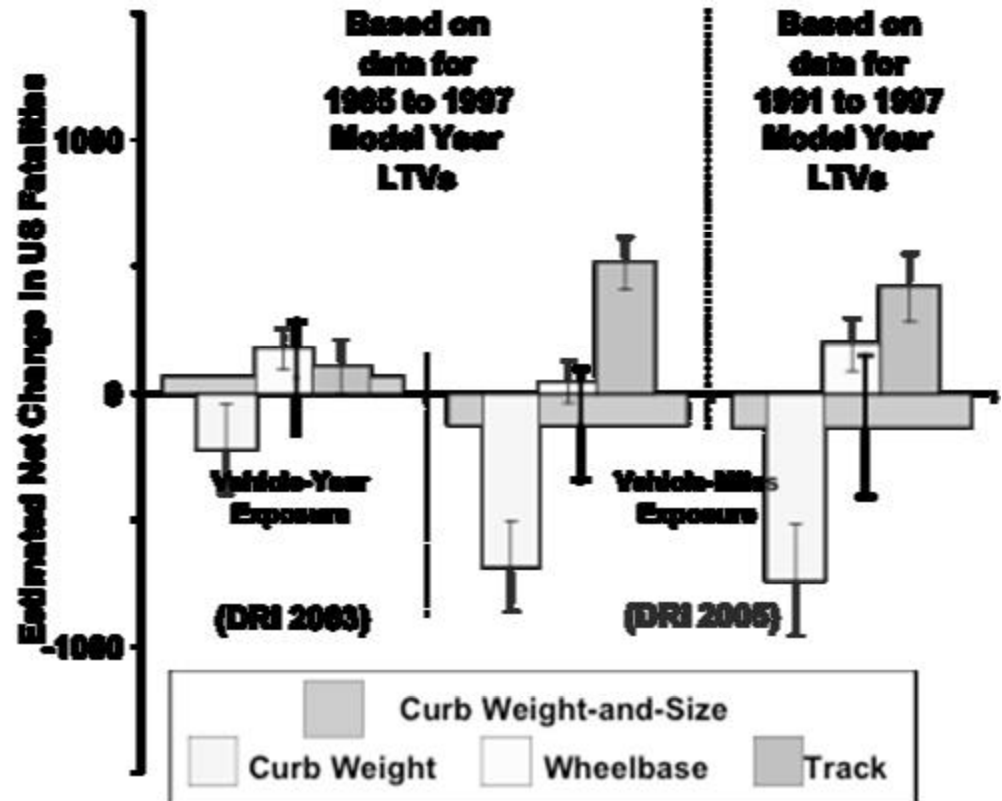
DRI: Additional Car Results

- Results for the 1991 to 1998 MY 4-door cars only:
 - Using logistic regression method to estimate IE/VR^{*}
 - Data removed for:
 - 1985-90 MY cars
 - Non 4-door cars
 - “Police” cars
 - Results may not be representative of other car types
 - But weight and size reduction trends are opposite and stable



DRI: Additional LT Results

- Sensitivity of the LT results to:
 - Measure of exposure
 - IE/VRV regression method
 - LT model years



- Weight vs size trends are opposite and are stable
 - “Weight” reduction decreases fatalities
 - “Wheelbase” and/or “track” reduction increases fatalities

Supporting Work

Other researchers have also concluded that modern safety is primarily a design issue, not a weight issue

– Dr. Leonard Evans

- 1982 - Car mass and likelihood of occupant fatality, SAE 820807
 - “the likelihood that a car has an occupant or driver fatality is related to the mass of the car.”
- 2004 - How to Make a Car Lighter and Safer, SAE 2004-01-1172

– Robert B. Noland, Motor Vehicle Fuel Efficiency and Traffic Fatalities, The Energy Journal, Vol. 25, No. 4, 2004

- “Overall results suggest that while there may have been an association between fleet fuel efficiency improvements and traffic fatalities in the 1970s, this has largely disappeared.”

– Delannoy, P. and Faure, J., "Compatibility Assessment Proposal from Real Life Accident (94)", Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, 2003

2010 NHTSA Safety Study

- Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991-1999 and Other Passenger Cars and LTVs. March 24, 2010 Charles J. Kahane, NCSA, NHTSA
- Significant movement from earlier studies:
 - “It is possible and appropriate to separate the effects of mass reductions from the effect of footprint reductions”
 - Included 2-door cars, except for muscle cars
- Differences in methodology continue to exist
 - NHTSA is in the process of issuing a contract for an “independent review of recent statistical analyses of relationships between vehicles' curb weight, track width, wheelbase, and fatality rates.
- Latest report did not support the use of its own model; instead, substituted "expert opinion" for specific coefficients in the model

Overall Fatality Estimates

Fatality Increase per 100-Pound Reduction (%)¹⁴⁵

	Actual Regression Result Scenario	NHTSA Expert Opinion Upper-Estimate Scenario ¹⁴⁶	NHTSA Expert Opinion Lower-Estimate Scenario
Cars < 2,950 pounds	2.21	2.21	1.02
Cars ≥ 2,950 pounds	0.90	0.90	0.44
LTVs < 3,870 pounds	0.17	0.55	0.41
LTVs ≥ 3,870 pounds	-1.90	-0.62	-0.73

Estimated lifetime reduction in fatalities compared to 2011MY baseline fleet

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
NPRM “Worst Case”	34	54	194	313	493
NHTSA Expert Opinion Final Rule Upper Estimate	9	14	26	24	22
NHTSA Expert Opinion Final Rule Lower Estimate	2	4	(17)	(53)	(80)
Actual Regression Result Scenario	0	2	(94)	(206)	(301)

NHTSA Ignored their own model and established “expert option” upper and lower estimates.

Primary factor:
Eliminated rollover fatalities reductions with weight reduction

Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule
[EPA-HQ-OAR-2009-0472; FRL_8959-4; NHTSA-2009-0059] RIN 2060-AP58; RIN 2127-AK50

Expert Opinion Changes - Cars

Cars < 2,950 pounds – Fatality increase per 100-pound mass reduction, no change in footprint

Crash Type	Annual Baseline ⁴³⁰ Crash Fatalities	Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
		Actual Regression Result Scenario		Upper-Estimate Scenario ⁴³¹		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	995	-1.59	-15.8	-1.59	-15.8	0	0
Fixed object	3,357	.64	21.5	.64	21.5	.34	11.4
Ped/bike/motorcycle	1,741	3.23	56.2	3.23	56.2	0	0
Heavy truck	1,148	3.98	45.7	3.98	45.7	.53	6.1
Car < 2,950 pounds	934	1.97	18.7	1.97	18.7	0	0
Car ≥ 2,950 pounds	1,342	.99	13.3	.99	13.3	0	0
LTV	4,091	3.95	161.6	3.95	161.6	2.96	121.1
Overall	13,608	2.21	300.9	2.21	300.9	1.02	138.6

Cars > 2,950 pounds – Fatality increase per 100-pound mass reduction, no change in footprint

Crash Type	Annual Baseline ⁴³² Crash Fatalities	Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
		Actual Regression Result Scenario		Upper-Estimate Scenario ⁴³³		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	715	-1.33	-9.5	-1.33	-9.5	0	0
Fixed object	2,822	1.09	30.8	1.09	30.8	.34	9.6
Ped/bike/motorcycle	1,349	-.60	-8.1	-.60	-8.1	0	0
Heavy truck	822	.84	6.9	.84	6.9	.53	4.4
Car < 2,950 pounds	1,342	.74	9.9	.74	9.9	0	0
Car ≥ 2,950 pounds	677	1.47	10.0	1.47	10.0	0	0
LTV	3,157	1.82	57.5	1.82	57.5	1.08	34.1
Overall	10,844	.90	97.5	.90	97.5	.44	48.1

Expert Opinion Changes – Light Trucks

LDTs < 3,870 pounds – Fatality increase per 100-pound mass reduction, no change in footprint

Crash Type	Annual Baseline ⁴³⁴ Crash Fatalities	Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
		Actual Regression Result Scenario		Upper-Estimate Scenario		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	1,319	-4.61	-60.8	0	0	0	0
Fixed object	1,687	.08	1.3	.35	5.9	0	0
Ped/bike/motorcycle	1,148	.51	5.9	0	0	0	0
Heavy truck	584	4.43	25.9	1.38	8.1	.53	3.1
Car	2,062	-.17	-3.5	0	0	0	0
LTV < 3,870 pounds ⁴³⁵	247	6.00	14.8	0	0	0	0
LTV ≥ 3,870 pounds	1,010	3.00	30.3	3.00	30.3	3.00	30.3
Overall	8,057	.17	13.9	.55	44.3	.41	

LDTs > 3,870 pounds – Fatality increase per 100-pound mass reduction, no change in footprint

Crash Type	Annual Baseline ⁴³⁶ Crash Fatalities	Scenarios – Effects of 100-Pound Reductions While Maintaining Footprint					
		Actual Regression Result Scenario		Upper-Estimate Scenario		Lower-Estimate Scenario	
		Percent Change	Fatality Change	Percent Change	Fatality Change	Percent Change	Fatality Change
First-event rollover	2,183	-4.94	-107.8	0	0	0	0
Fixed object	2,639	-.55	-14.5	.35	9.2	0	0
Ped/bike/motorcycle	2,043	-.48	-9.8	0	0	0	0
Heavy truck	860	-.67	-5.8	1.38	11.9	.53	4.6
Car	5,186	-1.78	-92.3	-1.78	-92.3	-1.78	-92.3
LTV < 3,870 pounds ⁴³⁷	1,010	-1.92	-19.4	-1.92	-19.4	-1.92	-19.4
LTV ≥ 3,870 pounds	784	-3.84	-30.1	0	0	0	0
Overall	14,705	-1.90	-279.7	-.62	-90.6	-.73	-107.1

Future Safety Analyses

- Tom Wenzel is analyzing safety for the U.S. DOE
- NHTSA is contracting for an independent review of the analyses of wheelbase, curb weight and track on fatalities
 - “Review the validity of the studies in modeling the data upon which they are based, clearly explain their methodology, exploratory data analysis and their potential utility in predicting the possible effects on fatalities and injuries of weight reductions for future vehicles.”
 - Work to begin around June 24, 2010
- NHTSA updating safety data base for use in future analyses

Overall Safety Considerations

- Irrespective of fuel economy, efforts are being made by all manufacturers to improve the compatibility of all vehicles through improvements in the stiffness and geometric compatibility of their protective and occupant compartment structures.
- Advanced crash safety technology and crash avoidance technology will not change the relationship between safety and size/weight, but they will reduce the overall safety impact by reducing the magnitude of all injuries.
- Lightweight materials can both reduce overall fatalities and improve fuel economy

Summary

- **Better policy can drive improvements in both vehicle fuel economy and safety – no trade-off is required.**
 - Most technologies to increase fuel economy do not affect safety; most technologies to increase safety do not affect fuel economy.
- Reducing the weight of heavier SUVs and trucks increases fuel economy and improves the safety of all vehicles on the road.
- Advanced materials can decouple size from mass (weight), creating important new possibilities for simultaneously improving both fuel economy and safety without compromising functionality.

Thank You

More Information

DRI Reports:

2002 – DRI-TR-02-02 (16318-2)*

2003 – DRI-TR-03-01 (16318-3)*

2004 – DRI-TR-04-02 (16318-7)*

2005 – DRI-TR-05-01 (16318-17)*

2004 – DRI-TR-04-04-2 (16128-1452)*

- NHTSA Docket Number

ICCT report, "Sipping Fuel and Saving Lives: Increasing Fuel Economy without Sacrificing Safety," D. Gordon, D. Greene, M. Ross, T. Wenzel. 2007.